



(12) **United States Patent**
Wu et al.

(10) **Patent No.:** **US 9,231,071 B2**
(45) **Date of Patent:** **Jan. 5, 2016**

(54) **SEMICONDUCTOR STRUCTURE AND
MANUFACTURING METHOD OF THE SAME**

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(*) Notice: Subject to any disclaimer, the term of this
patent is extended or adjusted under 35
U.S.C. 154(b) by 63 days.

(21) Appl. No.: **14/187,701**

(22) Filed: **Feb. 24, 2014**

(65) **Prior Publication Data**

US 2015/0243754 A1 Aug. 27, 2015

(51) **Int. Cl.**
H01L 21/44 (2006.01)
H01L 21/70 (2006.01)
H01L 29/49 (2006.01)
H01L 29/40 (2006.01)

(52) **U.S. Cl.**
CPC **H01L 29/4966** (2013.01); **H01L 29/401**
(2013.01); **H01L 29/4983** (2013.01)

(58) **Field of Classification Search**
CPC H01L 21/28088; H01L 21/823828
USPC 438/658; 257/407
See application file for complete search history.

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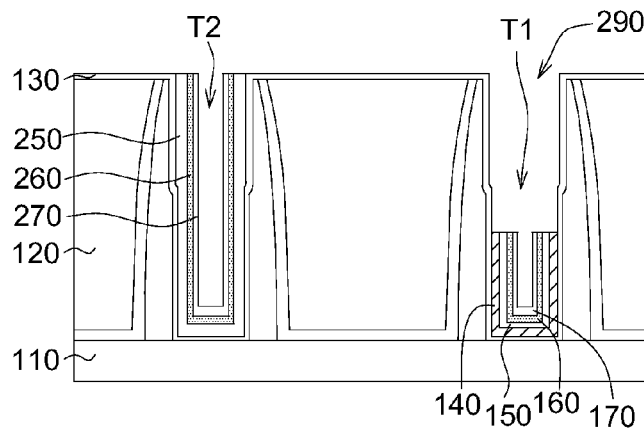
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(57) **ABSTRACT**

A semiconductor structure and a manufacturing method thereof are disclosed. The semiconductor structure includes an isolation layer, a gate dielectric layer, a first work function metal, a first bottom barrier layer, a second work function metal, and a first top barrier layer. The isolation layer is formed on a substrate and has a first gate trench. The gate dielectric layer is formed in the first gate trench. The first work function metal is formed on the gate dielectric layer in the first gate trench. The first bottom barrier layer is formed on the first work function metal. The second work function metal is formed on the first bottom barrier layer. The first top barrier layer is formed on the second work function metal.

14 Claims, 6 Drawing Sheets



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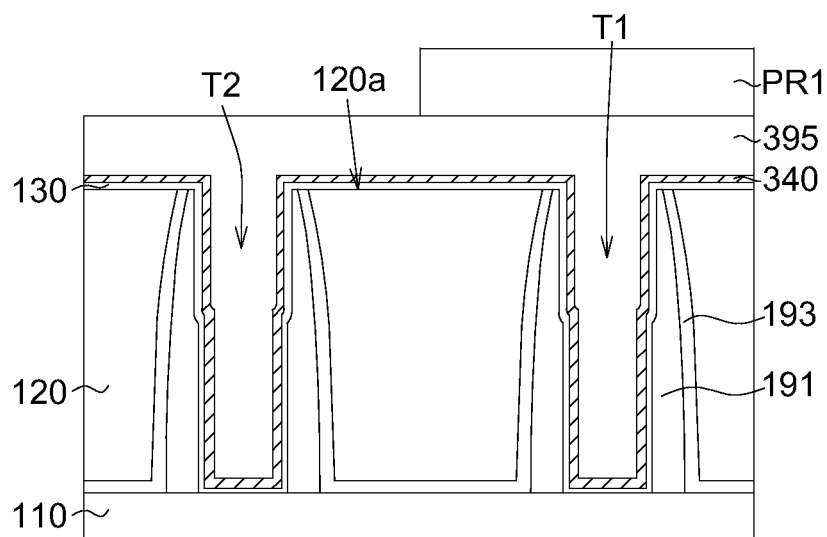
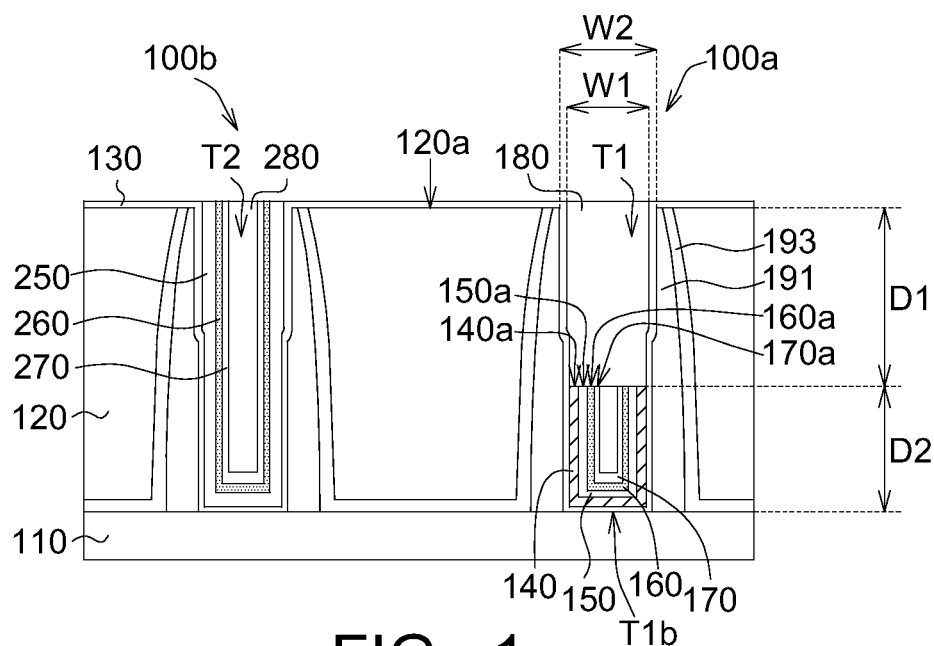
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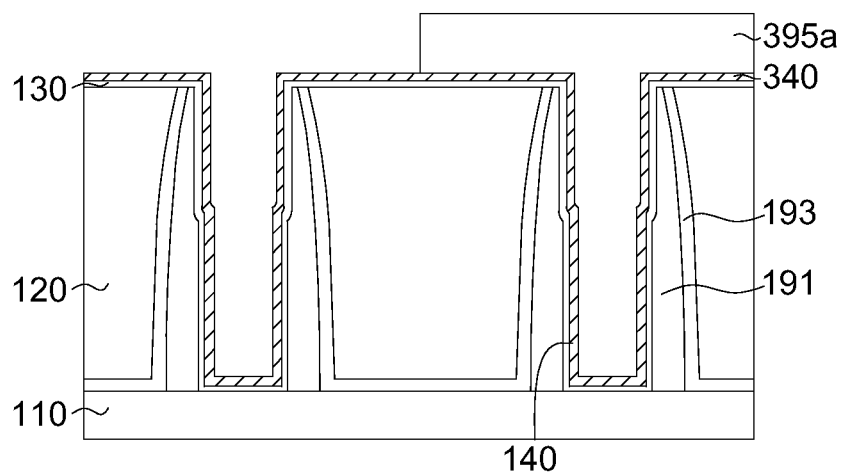


FIG. 2B

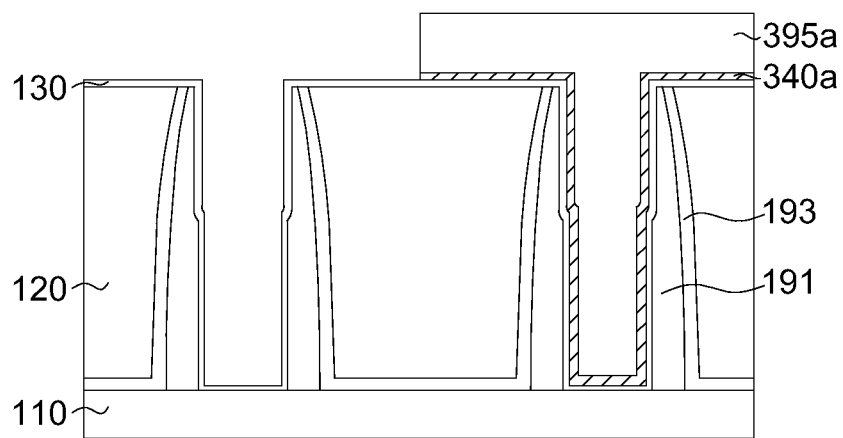


FIG. 2C

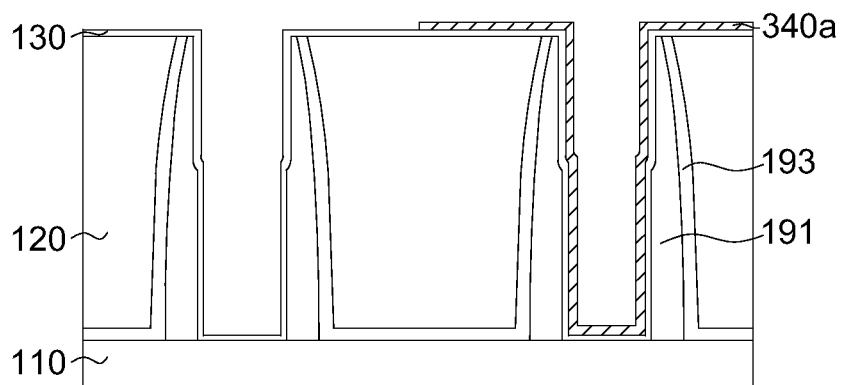


FIG. 2D

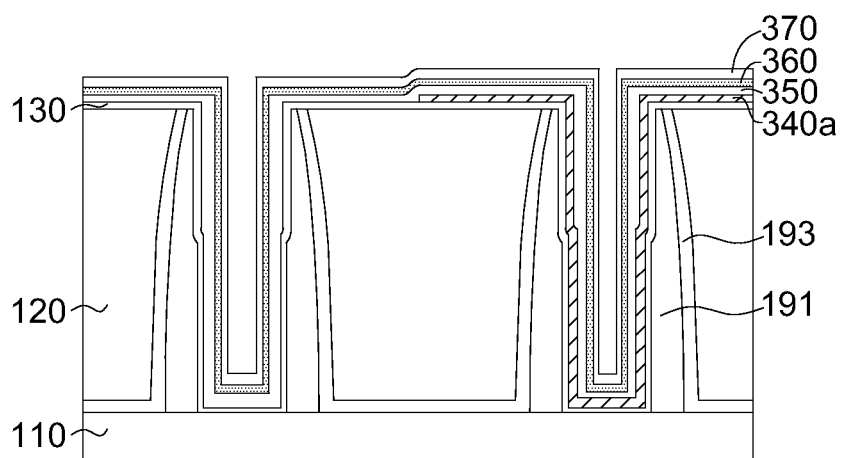


FIG. 2E

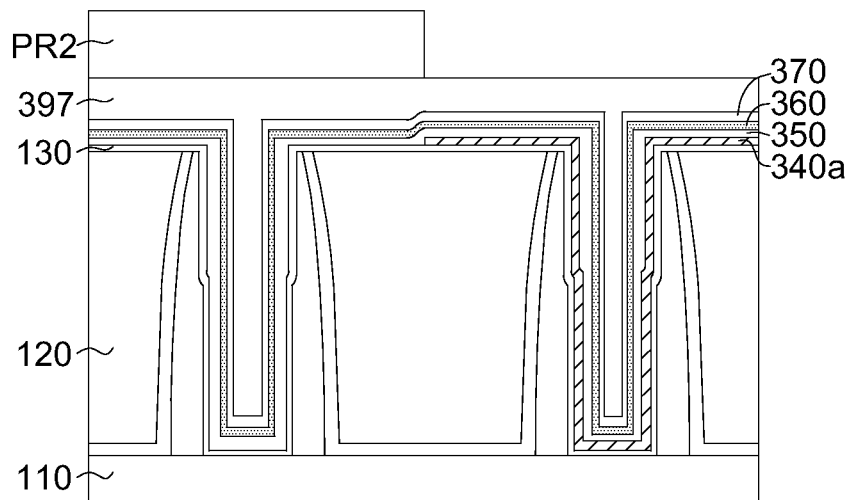


FIG. 2F

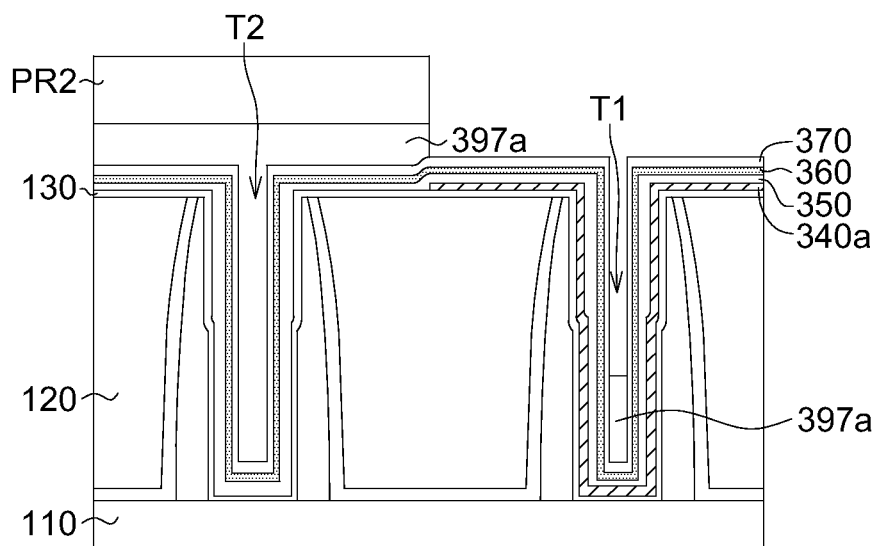


FIG. 2G

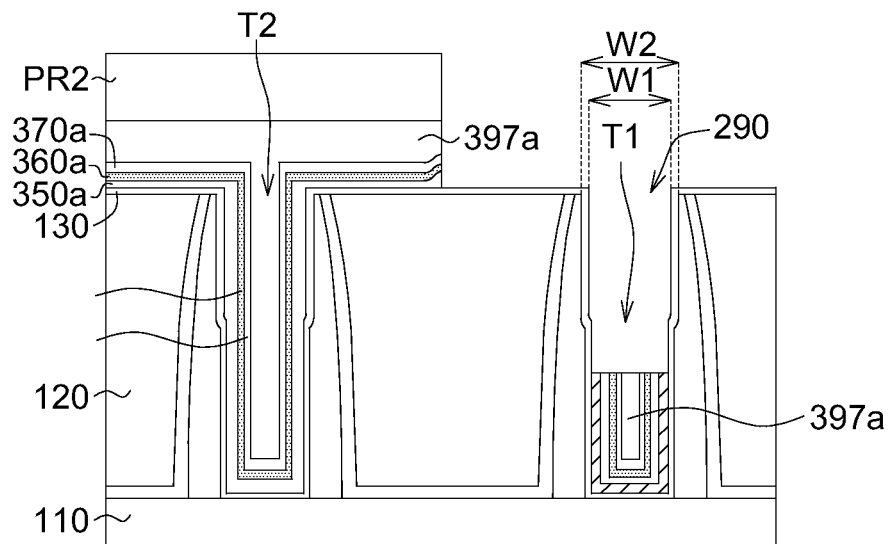


FIG. 2H

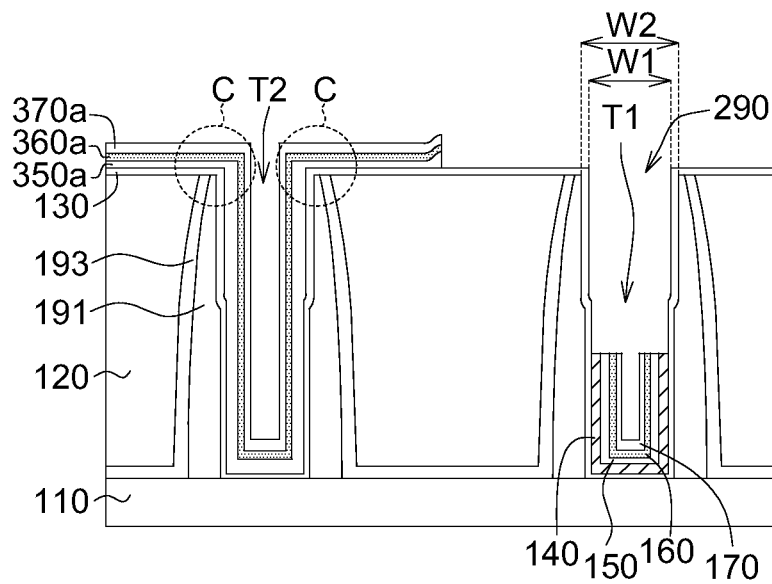


FIG. 21

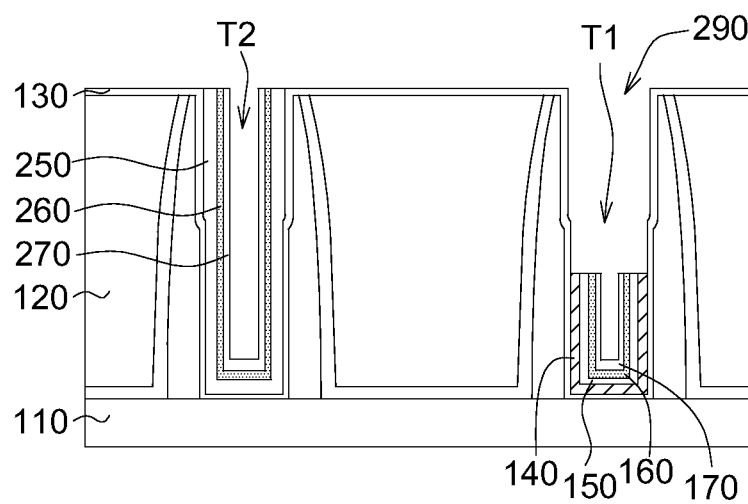


FIG. 2J

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SEMICONDUCTOR STRUCTURE AND MANUFACTURING METHOD OF THE SAME

BACKGROUND

1. Technical Field

The disclosure relates in general to a semiconductor structure and a manufacturing method thereof, and more particularly to a semiconductor structure with a filling metal and a manufacturing method thereof.

2. Description of the Related Art

While the size of semiconductor devices, such as metal-oxide-semiconductors (MOS), scales down, the conventional polysilicon gates have faced a variety of problems. Accordingly, work function metals along with high-K gate dielectric layers are used in the semiconductor devices for replacing the conventional polysilicon gates and being used as control electrodes.

However, in such case, the manufacturing process as well as the structures of replaced metal gates is critical. Therefore, there is always a continuing need in improving the semiconductor processing to develop semiconductor devices with metal gates for providing superior performance and reliability.

SUMMARY OF THE INVENTION

The disclosure is directed to a semiconductor structure and a manufacturing method thereof. According to some embodiments of the present disclosure, the semiconductor structure is provided with a superior filling capacity, a filling metal with intact integrity, and the device adopting such semiconductor structure has improved performance and reliability.

According to an embodiment of the present disclosure, a semiconductor structure is disclosed. The semiconductor structure includes an isolation layer, a gate dielectric layer, a first work function metal, a first bottom barrier layer, a second work function metal, and a first top barrier layer. The isolation layer is formed on a substrate and has a first gate trench. The gate dielectric layer is formed in the first gate trench. The first work function metal is formed on the gate dielectric layer in the first gate trench. The first bottom barrier layer is formed on the first work function metal. The second work function metal is formed on the first bottom barrier layer. The first top barrier layer is formed on the second work function metal.

According to another embodiment of the present disclosure, a manufacturing method of a semiconductor structure is disclosed. The manufacturing method includes the following steps: forming an isolation layer on a substrate, comprising forming a first gate trench in the isolation layer; forming a gate dielectric layer in the first gate trench; forming a first work function metal on the gate dielectric layer in the first gate trench; forming a first bottom barrier layer on the first work function metal; forming a second work function metal on the first bottom barrier layer; and forming a first top barrier layer on the second work function metal.

The disclosure will become apparent from the following detailed description of the preferred but non-limiting embodiments. The following description is made with reference to the accompanying drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 shows a schematic diagram of a semiconductor structure 100 according to an embodiment of the present disclosure; and

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FIGS. 2A-2J illustrate a manufacturing method of the semiconductor structure according to an embodiment of the present disclosure.

DETAILED DESCRIPTION OF THE INVENTION

In some embodiments of the present disclosure, the semiconductor structure is provided with a superior filling capacity, a filling metal with intact integrity, and the device adopting such semiconductor structure has improved performance and reliability. The embodiments are described in details with reference to the accompanying drawings. The procedures and details of the method of the embodiments are for exemplification only, not for limiting the scope of protection of the disclosure. Moreover, the identical elements of the embodiments are designated with the same reference numerals. Also, it is also important to point out that the illustrations may not be necessarily be drawn to scale, and that there may be other embodiments of the present disclosure which are not specifically illustrated. Thus, the specification and the drawings are to be regarded as an illustrative sense rather than a restrictive sense.

FIG. 1 shows a schematic diagram of a semiconductor structure 100 according to an embodiment of the present disclosure. As shown in FIG. 1, the semiconductor structure 100 includes an isolation layer 120, a gate dielectric layer 130, a first work function metal 140, a first bottom barrier layer 150, a second work function metal 160, and a first top barrier layer 170. The isolation layer 120 is formed on a substrate 110 and has a first gate trench T1. The gate dielectric layer 130 is formed in the first gate trench T1. The first work function metal 140 is formed on the gate dielectric layer 130 in the first gate trench T1. The first bottom barrier layer 150 is formed on the first work function metal 140. The second work function metal 160 is formed on the first bottom barrier layer 150. The first top barrier layer 170 is formed on the second work function metal 160. In other words, as shown in FIG. 1, in the present embodiment, the first bottom barrier layer 150 is formed between the first work function metal 140 and the second work function metal 160.

In the embodiment, the isolation layer 120 is such as an inter-layer dielectric (ILD) layer, and the gate dielectric layer 130 is formed from at least a high-k material, such as rare earth metal oxide. In some embodiments, the gate dielectric layer 130 may include HfO_2 , HfSiO_4 , HfSiON , Al_2O_3 , La_2O_3 , Ta_2O_5 , Y_2O_3 , ZrO_2 , SrTiO_3 , ZrSiO_4 , HfZrO_4 , SBT, PZT, BST, or the combinations thereof. In an embodiment, the isolation layer 120 has a thickness of such as about 1050 Å, and the substrate 110 has a thickness of about 300 Å.

In the embodiment, the first work function metal 140 is such as a p type work function metal and may include TiN, TaN, TiC, TaC, WC, TiAlN, or the combinations thereof, and the second work function metal 160 is such as an n type work function metal and may include TiAl, ZrAl, WAl, TaAl, HfAl, or the combinations thereof.

In some embodiments of the present disclosure, the first bottom barrier layer 150 and the first top barrier layer 170 may independently comprise TiN, TaN, Ti/TiN, Ta/TaN, or the combinations thereof.

As shown in FIG. 1, in the embodiment, the isolation layer 130 may further has a second gate trench T2 which is separated from the first gate trench T1, and the gate dielectric layer 130 is further formed in the second gate trench T2.

In the embodiment, the semiconductor structure 100 may further include a second bottom barrier layer 250, a third work function metal 260, and a second top barrier layer 270. The second bottom barrier layer 250 is formed on the gate

dielectric layer **130** in the second gate trench **T2**. The third work function metal **260** is formed on the second bottom barrier layer **250** and is the same type of a work function metal as is the second work function metal **160**. For example, the third work function metal **260** comprises the same material as that of the second work function metal **160**. The second top barrier layer **270** is formed on the third work function metal **260**. The second bottom barrier layer **250**, the third work function metal **260**, and the second top barrier layer **270** cover the sidewalls of the second gate trench **T2**.

In the embodiment, the second bottom barrier layer **250** and the second top barrier layer **270** may independently comprise TiN, TaN, Ti/TiN, Ta/TaN, or the combinations thereof.

As shown in FIG. 1, the first work function metal **140**, the first bottom barrier layer **150**, the second work function metal **160**, and the first top barrier layer **170** may have U-shaped profile structures. In the present embodiment, as shown in FIG. 1, the top surface **140a** of the first work function metal **140**, the top surface **150a** of the first bottom barrier layer **150**, the top surface **160a** of the second work function metal **160**, and the top surface **170a** of the first top barrier layer **170** are coplanar, and the top surfaces **140a**, **150a**, **160a**, **170a** are all below the top surface **120a** of the isolation layer **120**.

In an alternative embodiment (not shown), the semiconductor structure **100** further includes an additional top barrier layer (not shown) formed on the first work function metal **140**, the first bottom barrier layer **150**, the second work function metal **160**, and the first top barrier layer **170**. In the present embodiment, the additional top barrier layer may have a U-shaped profile structure and covers the sidewalls of the first gate trench **T1**, and a top surface of the additional top barrier layer is coplanar with the top surface **120a** of the isolation layer **120**.

In the present embodiment, the top surface **160a** of the second work function metal **160** and the top surface **120a** of the isolation layer **120** are separated by a first distance **D1**. The top surface **160a** of the second work function metal **160a** and the bottom surface **T1b** of the first gate trench **T1** are separated by a second distance **D2**. A ratio of the first distance **D1** to the second distance **D2** is about 0.5-0.9.

As shown in FIG. 1, the semiconductor structure **100** may further comprise a first filling metal **180** formed on the first top barrier layer **170** in the first gate trench **T1**. In the present embodiment, a ratio of the width **W1** of the first filling metal **180** to a width **W2** of the first gate trench **T1** is about 0.75-0.89.

As shown in FIG. 1, the semiconductor structure **100** may further comprise a second filling metal **280** formed on the second top barrier layer **270** in the second gate trench **T2**. In the embodiments of the present disclosure, the first filling metal **180** and the second filling metal **280** may independently include at least a material with low resistance and superior gap-filling characteristic, such as W, Al, TiAl, TiAlO, or combinations thereof.

As shown in FIG. 1, in the embodiment, the work function metal **140**, **160**, the barrier layers **150**, **170**, and the first filling metal **180** as whole form a first metal gate structure, and the work function metal **260**, the barrier layers **250**, **270**, and the second filling metal **280** as whole form a second metal gate structure. The semiconductor structure **100** may further include spacers **191** located beside the first metal gate structure and the second gate structure. In the embodiment, the spacer **191** may include SiN, SiO, SiON, or the combinations thereof.

As shown in FIG. 1, in the embodiment, the semiconductor structure **100** may further include a contact etch stop layer (CESL) **193** formed on the spacer **191** and the substrate **110**.

In an embodiment, the semiconductor structure **100** may be a CMOS FinFET including a PFET **100a** and a NFET **100b**. In the present embodiment, the PFET **100a** corresponds to the region of the first trench **T1**, and the NFET **100b** corresponds to the region of the second trench **T2**. The substrate **110** may be a portion of a fin of the CMOS FinFET.

The embodiments disclosed below are for elaborating a manufacturing method of the semiconductor structure **100** of the disclosure. However, the descriptions disclosed in the embodiments of the disclosure such as detailed manufacturing procedures are for illustration only, not for limiting the scope of protection of the disclosure. Referring to FIGS. 2A-2J, a manufacturing method of the semiconductor structure **100** according to an embodiment of the present disclosure is illustrated.

Referring to FIG. 2A, the spacers **191**, the CESL **193**, and the isolation layer **120** are formed on the substrate **110**. The formation of the isolation layer **120** comprises forming the first gate trench **T1** in the isolation layer **120**. Optionally, as shown in FIG. 2A, the second gate trench **T2** is further formed in the isolation layer **120**, wherein the second gate trench **T2** is separated from the first gate trench **T1**. Next, the gate dielectric layer **130** is formed in the first gate trench **T1**. In the present embodiment, the gate dielectric layer **130** is also formed in the second gate trench **T2** and on the top surface **120a** of the isolation layer **120**.

Still referring to FIG. 2A, a first work function metal material **340** is formed on the gate dielectric layer **130** in the first gate trench **T1** as well as in the second gate trench **T2**. Next, a mask layer **395** is formed on the gate dielectric layer **130**. As shown in FIG. 2A, the mask layer **395** covers the whole surface of the gate dielectric layer **130** and fills up the first gate trench **T1** and the second gate trench **T2**. In the embodiment, the mask layer **395** includes such as a dielectric anti-reflection coating (DARC), a light absorbing oxide (DUO), a bottom anti-reflective coating (BARC), or a sacrificial light absorbing material (SALM), but not limited thereto. And then, a photoresist **PR1** is disposed on the mask layer **395** corresponding to the region of the first gate trench **T1**. In the embodiment, the photoresist **PR1** is formed by such as a photolithography process.

Referring to FIG. 2B, a portion of the mask layer **395** exposed from the photoresist **PR1** is removed for forming a patterned mask layer **395a**. In the embodiment, the portion of the mask layer **395** is removed by such as a dry etching process. As shown in FIG. 2B, the patterned mask layer **395a** covers the region of the first gate trench **T1** and the layers formed therein. In an embodiment, the first work function metal material **340** is such as a p type work function metal material, and the patterned mask layer **395** covers the region corresponding to a PFET of a CMOS Fin FET.

Referring to FIG. 2C, a portion of the first work function metal material **340** exposed from the patterned mask layer **395a** is removed, and the remained first work function metal material **340a** is formed correspondingly above the first gate trench **T1**. Specifically, the portion of the first work function metal material **340** located in the second gate trench **T2** is removed, and the remained first work function metal material **340a** protects the layers formed in the first gate trench **T1**. In the embodiment, the portion of the first work function metal material **340** is removed by such as a wet cleaning process, wherein a suitable solvent is used for dissolving the to-be-removed portion.

Referring to FIG. 2D, the patterned mask layer **395a** is removed. In the embodiment, the patterned mask layer **395a** is removed by such as a wet cleaning process.

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Referring to FIG. 2E, a bottom barrier material **350**, a second work function metal material **360**, and a top barrier material **370** are formed on the gate dielectric layer **130** and the remained first work function metal material **340a**. In the present embodiment, the second work function metal material **360** is formed on the bottom barrier material **350**, and the top barrier material **370** is formed on the second work function metal material **360**. The materials **350**, **360**, and **370** are filled in the first gate trench **T1** and in the second gate trench **T2**.

Referring to FIG. 2F, after the materials **350**, **360**, and **370** are formed on the gate dielectric layer **130** and filled in the first gate trench **T1** and in the second gate trench **T2**, a mask layer **397** is formed on the top barrier material **370**. As shown in FIG. 2F, the mask layer **397** covers the whole surface of the top barrier material **370** and fills up the first gate trench **T1** and the second gate trench **T2**. In the embodiment, the mask layer **397** includes such as a dielectric anti-reflection coating (DARC), a light absorbing oxide (DUO), a bottom anti-reflective coating (BARC), or a sacrificial light absorbing material (SALM), but not limited thereto. And then, a photoresist PR2 is disposed on the mask layer **397** corresponding to the region of the second gate trench **T2**. In the embodiment, the photoresist PR2 is formed by such as a photolithography process.

Referring to FIG. 2G, a portion of the mask layer **397** exposed from the photoresist PR2 is removed for forming a patterned mask layer **397a**. As shown in FIG. 2G, the patterned mask layer **397a** covers the region of the second gate trench **T2** and the layers (gate dielectric layer **130** and materials **350**, **360**, and **370**) formed therein, and the patterned mask layer **397a** fills up a portion of the first gate trench **T1**. In the embodiment, the portion of the mask layer **397** is removed by such as a dry etching process.

Referring to FIG. 2H, the remained first work function metal material **340a** exposed from the patterned mask layer **397a** is partially removed for forming the first work function metal **140**, the bottom barrier material **350** exposed from the patterned mask layer **397a** is partially removed for forming the first bottom barrier layer **150**, the second work function metal material **360** exposed from the patterned mask layer **397a** is partially removed for forming the second work function metal **160**, and the top barrier material **370** exposed from the patterned mask layer **397a** is partially removed for forming the first top barrier layer **170**. The first work function metal **140** is formed on the gate dielectric layer **130** in the first gate trench **T1**, the first bottom barrier layer **150** is formed on the first work function metal **140**, the second work function metal **160** is formed on the first bottom barrier layer **150**, and the first top barrier layer **170** is formed on the second work function metal **160**.

In the present embodiment, the remained first work function metal material **340a**, the bottom barrier material **350**, the second work function metal material **360**, and the top barrier material **370** exposed from the patterned mask layer **397a** are partially removed in the same manufacturing process. Since the remained first work function metal material **340a**, the bottom barrier material **350**, the second work function metal material **360**, and the top barrier material **370** are pulled down all together in the same manufacturing process, as shown in FIG. 2H, a large opening with the width **W1** is formed. In other words, the sidewalls of the first gate trench **T1** are not fully covered by the bottom barrier material **350**, the second work function metal material **360**, and the top barrier material **370**, leaving a relatively larger opening **290** within the first gate trench **T1**. In the embodiment, since the original width **W2** of the first gate trench **T1** is only reduced by the formation

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of the gate dielectric layer **130** on the sidewalls of the first gate trench **T1**, the as-formed large opening **290** is provided with a superior filling capacity for, for example, a metal material. In the present embodiment, a ratio of the width **W1** of the opening **290** to the original width **W2** of the first gate trench **T1** is such as about 0.75-0.89.

Referring to FIG. 2I, the patterned mask layer **397a** is removed. In the embodiment, the patterned mask layer **397a** is removed by such as a dry etching process. In this step, the remained bottom barrier material **350a**, the remained second work function metal material **360a**, and the remained top barrier material **370a** cover the corner portions **C** (e.g. the gate dielectric layer **130** and the spacers **191**) of the second gate trench **T2**; therefore, the structure of the corner portions **C** of the second gate trench **T2** is not directly bombard by ions from the dry etching process, and the damage to the structure of the corner portions **C** of the second gate trench **T2** which may be caused by a dry etching process is prevented. In this regard, the remained bottom barrier material **350a**, the remained second work function metal material **360a**, and the remained top barrier material **370a** on the gate dielectric layer **130** in the second gate trench **T2** are used not only as the work function metal and barrier layers for the NFET **100b**, as previously described, but also as the protection layers for the structure of the second gate trench **T2** in the manufacturing process. As the structure of the second gate trench **T2** is sufficiently protected, the structure of the second filling metal **280**, which will be formed in the second gate trench **T2** in the following process, can maintain its intact integrity. In an embodiment, the second filling metal **280** is such as the replacement metal gate of a NFET or CMOS FinFET; accordingly, the intact integrity of the second filling metal **280** results in no height loss in the metal gate, and the performance and the reliability of the CMOS FinFET are thus improved.

Referring to FIG. 2J, a planarization process is performed to partially remove the remained bottom barrier material **350a**, the remained second work function metal material **360a**, and the remained top barrier material **370a** located correspondingly above the second gate trench **T2**. In the embodiment, the planarization process is such as a CMP process. The remained bottom barrier material **350a** is partially removed for forming the second bottom barrier layer **250** on the gate dielectric layer **130** in the second gate trench **T1**. The remained second work function metal material **360a** is partially removed for forming the third work function metal **260** on the second bottom barrier layer **250**. The remained top barrier material **370a** is partially removed for forming the second top barrier layer **270** on the third work function metal **260**. As shown in FIG. 2J, the second bottom barrier layer **250**, the third work function metal **260**, and the second top barrier layer **270** cover the sidewalls of the second gate trench **T2**.

Next, referring to FIG. 1, a filling metal material (not shown) is formed on the first top barrier layer **170** in the first gate trench **T1** and on the second top barrier layer **270** in the second gate trench **T2**. The filling metal material fills up the first gate trench **T1** and the second gate trench **T2**. As the remained first work function metal material **340a**, the bottom barrier material **350**, the second work function metal material **360**, and the top barrier material **370** are pulled down all together in the same manufacturing process to form a large opening **290** with the width **W1**, the gap filling capacity for the filling metal material in the first gate trench **T1** is greatly improved.

And then, a planarization process is performed to remove unnecessary portions of the filling metal material for forming the first filling metal **180** in the first gate trench **T1** and the

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second filling metal **280** in the second gate trench **T2**. As such, the semiconductor structure **100** as shown in FIG. **1** is manufactured.

In an alternative embodiment, an additional top barrier layer (not shown) is formed on the first work function metal **140**, the first bottom barrier layer **150**, the second work function metal **160**, and the first top barrier layer **170** before the filling metal material is filled in the first gate trench **T1** and the second gate trench **T2**. In the present embodiment, the additional top barrier layer covers the sidewalls of the first gate trench **T1**, and a top surface of the additional top barrier layer is coplanar with the top surface **120a** of the isolation layer **120**.

While the invention has been described by way of example and in terms of the preferred embodiment(s), it is to be understood that the invention is not limited thereto. On the contrary, it is intended to cover various modifications and similar arrangements and procedures, and the scope of the appended claims therefore should be accorded the broadest interpretation so as to encompass all such modifications and similar arrangements and procedures.

What is claimed is:

1. A semiconductor structure, comprising:
 - an isolation layer formed on a substrate, wherein the isolation layer has a first gate trench and a second gate trench separated from the first gate trench;
 - a gate dielectric layer formed in the first gate trench and in the second gate trench;
 - a first work function metal formed on the gate dielectric layer in the first gate trench;
 - a first bottom barrier layer formed on the first work function metal;
 - a second work function metal formed on the first bottom barrier layer;
 - a first top barrier layer formed on the second work function metal;
 - a second bottom barrier layer formed on the gate dielectric layer in the second gate trench;
 - a third work function metal formed on the second bottom barrier layer, the third work function metal comprising the same material with that of the second work function metal; and
 - a second top barrier layer formed on the third work function metal;
 wherein the second bottom barrier layer, the third work function metal, and the second top barrier layer cover the sidewalls of the second gate trench.
2. The semiconductor structure according to claim 1, wherein the first work function metal, the first bottom barrier layer, the second work function metal, and the first top barrier layer have U-shaped profile structures.
3. The semiconductor structure according to claim 1, wherein top surfaces of the first work function metal, the first bottom barrier layer, the second work function metal, and the first top barrier layer are coplanar and below a top surface of the isolation layer.
4. The semiconductor structure according to claim 1, wherein a ratio of a first distance between the top surface of the second work function metal and the top surface of the isolation layer to a second distance between the top surface of the second work function metal and the bottom surface of the first gate trench is 0.5-0.9.
5. The semiconductor structure according to claim 1, further comprising:

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a first filling metal formed on the first top barrier layer in the first gate trench, wherein a ratio of a width of the first filling metal to a width of the first gate trench is 0.75-0.89.

6. The semiconductor structure according to claim 1, further comprising:

a second filling metal formed on the second top barrier layer in the second gate trench.

7. The semiconductor structure according to claim 1, wherein the first bottom barrier layer and the first top barrier layer independently comprise TiN, TaN, Ti/TiN, Ta/TaN, or the combinations thereof.

8. A manufacturing method of a semiconductor structure, comprising:

forming an isolation layer on a substrate, comprising forming a first gate trench and a second gate trench in the isolation layer, the second gate trench being separated from the first gate trench;

forming a gate dielectric layer in the first gate trench and in the second gate trench;

forming a first work function metal on the gate dielectric layer in the first gate trench;

forming a first bottom barrier layer on the first work function metal;

forming a second work function metal on the first bottom barrier layer;

forming a first top barrier layer on the second work function metal;

forming a second bottom barrier layer on the gate dielectric layer in the second gate trench;

forming a third work function metal on the second bottom barrier layer, the third work function metal having the same material with that of the second work function metal; and

forming a second top barrier layer on the third work function metal;

wherein the second bottom barrier layer, the third work function metal, and the second top barrier layer cover the sidewalls of the second gate trench.

9. The manufacturing method according to claim 8, wherein the first work function metal, the first bottom barrier layer, the second work function metal, and the first top barrier layer have U-shaped profile structures.

10. The manufacturing method according to claim 8, wherein top surfaces of the first work function metal, the first bottom barrier layer, the second work function metal, and the first top barrier layer are coplanar and below a top surface of the isolation layer.

11. The manufacturing method according to claim 8, wherein a ratio of a first distance between the top surface of the second work function metal and the top surface of the isolation layer to a second distance between the top surface of the second work function metal and the bottom surface of the first gate trench is 0.5-0.9.

12. The manufacturing method according to claim 8, further comprising:

forming a first filling metal on the first top barrier layer in the first gate trench, wherein a ratio of a width of the first filling metal to a width of the first gate trench is 0.75-0.89.

13. The manufacturing method according to claim 8, further comprising:

forming a second filling metal on the second top barrier layer in the second gate trench.

14. The manufacturing method according to claim 8, wherein the first bottom barrier layer and the first top barrier layer independently comprise TiN, TaN, Ti/TiN, Ta/TaN, or the combinations thereof.

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